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DETECTION AND CROSS-FIXING COVER FOR VARIOUS ARRANGEMENTS OF SONAR ARRAYS [R]

BY

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JULY 1976

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DETECTION AND CROSS-FIXING COVER FOR VARIOUS ARRANGEMENTS OF SONAR ARRAYS [R]

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(8)

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ABSTRACT

Considering only the problem of detection, the most economical arrangement of a number of arrays to give nominally full cover is a simple triangular lattice. In the more important problem of cross-fixing the best practical solution is a simple square lattice, with detection range approximately equal to the spacing.

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14 pages
5 figures

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INTRODUCTION

What lattice arrangement of sonar or other arrays is best for detection and cross-fixing and what should be the spacing? One place where this question arises is in the design of systems of fixed passive sonar surveillance arrays. It is not thought that performance should be very sensitive to the arrangement pattern, but there is much at stake, and it is worth trying to get it right. Some very simple ideas are set out here, but they do lead to definite answers.

This paper is one of four treating successive steps in the conceptual design of an array system -

(a) The decision on scale: should there be a few large arrays or many small arrays? [1].

(b) The detailed spatial arrangement of the array positions, discussed here.

(c) The relative orientations of the arrays to avoid ambiguity [2].

(d) The relative orientations of the arrays allowing also for location accuracy [3].

Of course these steps are not entirely independent, the answers have to be modified to allow for the topography of any area of interest, and there are many further stages in the full design.

2. ARRANGEMENTS CONSIDERING DETECTION ONLY

It will be assumed throughout this paper that what is wanted is an economical arrangement of arrays that allows at all times a high chance of detecting and perhaps locating a target within a given area. This immediately implies that the separation d between neighbouring arrays must be of the same order as the detection range r from one array. If the separation is much greater than this the detection probability at a given time will be low, when averaged over all the possible target positions, but the cumulative detection probability during a traversal of the area may still be reasonably high. Thus such a sparse array system may be useful, but it is not the case considered here.

This paper concentrates on the problem of area cover. There is an equivalent rather easier problem for a line or barrier system.

The paper starts by assuming in sections 2 and 3 a probability of detection which is unity out to a range r and zero thereafter, this is the so-called cookie-cutter model giving full cover within a circle.

In this section the conditions are considered for a good arrangement of arrays as regards detection, postponing considerations of locating till the next section.

If there are just two arrays with an ill-defined area it is wished to cover, then wasteful overlap can obviously be avoided by choosing $r < d/2$.

In a similar way we can envisage a large area and see how many arrays we can pack into it using a square matrix arrangement. This is a well-known packing problem, and avoiding overlap the maximum occurs at $r = d/2$ when the detection circles touch. The packing fraction F or fraction of the total area covered as regards detection is $F = \pi/4 = 0.79$. It may be argued that a target would have to pass through a detection area in order to reach one of the gaps among the detection circles, so that the effective probability of detection is unity. But this is really a special case of cumulative probability of detection, and in addition does not allow for the case of the intermittently noisy target and the other practical considerations introduced in section 4.

If we wish to have all the area covered as regards detection the most economical choice for a square lattice is $r = d/\sqrt{2}$. This is shown in figure 1, which may be thought of as an excerpt from an infinite lattice. This problem is the inverse of the usual packing problem. The packing fraction F may be defined as the ratio of the summed area cover of the arrays to the total area to be covered. It is now a measure of the apparent wastefulness due to overlap, and given here by $F = \pi/2 = 1.57$.

An alternative regular lattice is that based on triangles. With no overlap we have again $r = d/2$, leading to $F = \pi/2\sqrt{3} = 0.91$. This is an improvement on the square lattice. Figure 2 shows the arrangement for full cover, with $r = d/\sqrt{3}$ and $F = 2\pi/3\sqrt{3} = 1.21$. This is again better than the square lattice, since F should lie as close to unity as possible

We attach slightly more importance to the case with full cover than that with no overlap, but in either event it appears that as regards detection the triangular grid is superior to the square grid.

3. ARRANGEMENTS CONSIDERING CROSS-FIXING

To determine the position of a target it is necessary to take bearings from at least two arrays. In comparing the different arrangements for this we will take no quantitative account of the accuracy of the determination [3], nor the possibility of ambiguity in the position [2].

Let us start with the full cover criterion that every point in the area must be within range of two arrays. If there are just two arrays it is best to place them very close together, in contrast to the section 2 solution with $d = 2r$ as a minimum. The overall practical answer will of course depend on the relative weights attached to maximising the detection area as opposed to maximising the cross-fix area, with suitably-weighted account taken of location accuracy also.

With a square lattice the corresponding solution is to arrange the arrays in close pairs, and in comparison with the case of full cover for detection the number of necessary arrays is simply doubled We have again $r = d/\sqrt{2}$, but with $F = \pi = 3.14$. This system may have advantages as

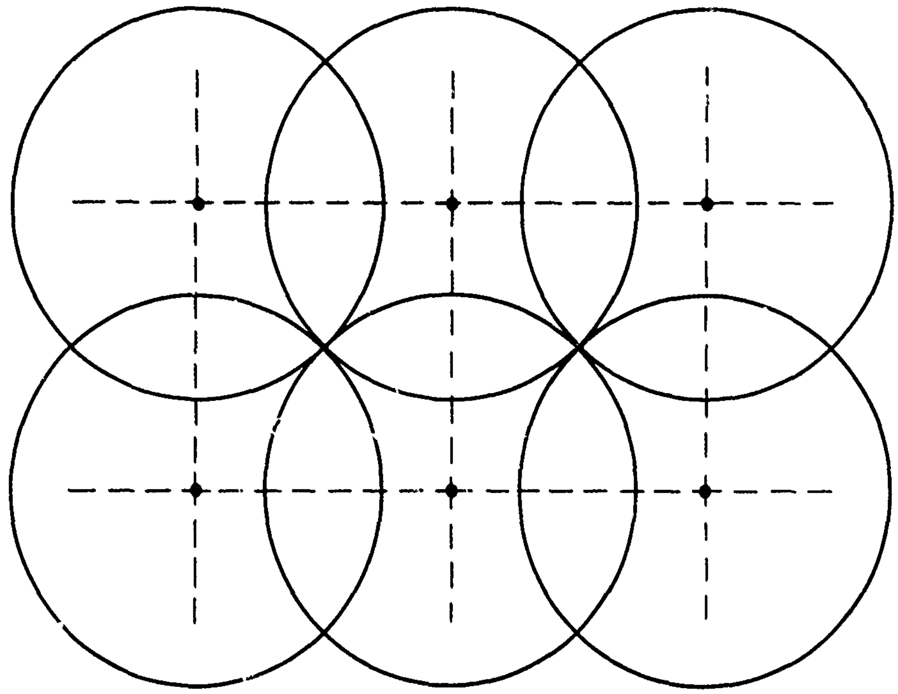

FIG 1 SQUARE LATTICE WITH GEOMETRY FOR FULL DETECTION COVER
(OR FOR CROSS-FIX COVER WITH "NO SUPERFLUITY")

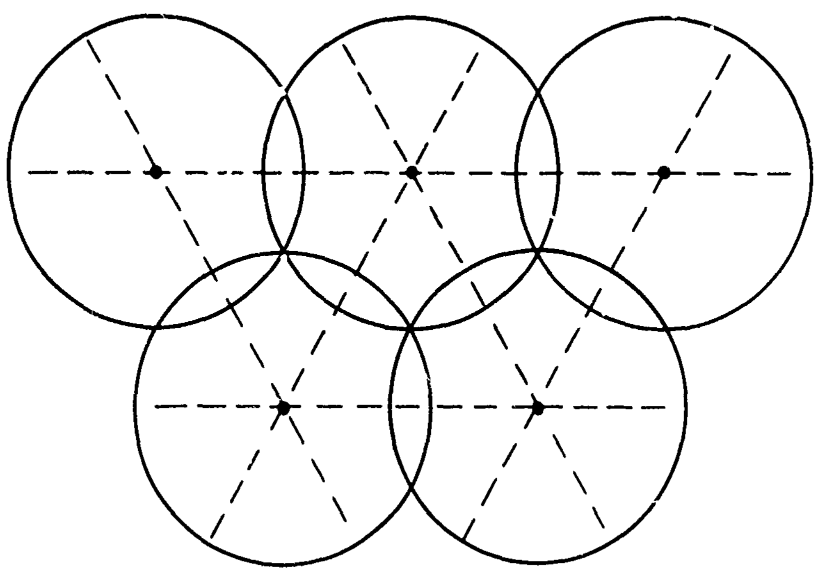

FIG 2 TRIANGULAR LATTICE WITH GEOMETRY FOR FULL DETECTION COVER
(OR FOR CROSS-FIX COVER WITH "NO SUPERFLUITY")

regards cabling and the possibility of coherence between the array pairs, but is not practical because the bearing lines will cut at too small an angle and will not allow a reasonable location accuracy. (Also a more realistic detection probability model than the cookie-cutter shows that, from the detection viewpoint, arrays should always be spaced fairly evenly, compare section 4.)

The alternative is to stick to the simple square lattice, changing the r/d ratio as necessary. Assuming a successful detection by the closest array, the worst case for detection by a second array occurs when the target is right next to the first array. This implies $r = d$ leading to $F = \pi = 3.14$, the same packing fraction as for the much less satisfactory system of close pairs. Figure 3 shows the theoretical number of simultaneous detections to be expected in different parts of the unit square, those above 2 being superfluous on our present narrow viewpoint. The area mean of these numbers is of course equal to F. Note that 2, 3 or 4 detections imply respectively 1, 3 or 6 pairs of arrays allowing separate cross-fixes.

For the triangular lattice a pair system needs $r = d/\sqrt{3}$, giving the good result $F = 4\pi/3\sqrt{3} = 2.42$. The simple triangular lattice with $r = d$ gives the poor result $F = 2\pi/\sqrt{3} = 3.63$, and is shown in figure 4.

We could have used here a criterion of no superfluity, ie as large as possible an area with two detections provided no part of it allows more than two detections. For both lattices the paired system then corresponds to the no-overlap condition of section 2, and the simple lattice to the full-cover condition of section 2. But the criterion of no superfluity is thought to be a poor one for several reasons, eg note the relatively small areas of cross-fixing shown in figures 1 and 2. The choice of the full-cover condition is thought to be even more natural for cross-fixing than for detection alone.

Based on F values we see that for cross-fixing the best arrangement from an academic point of view is the paired triangular grid, but the best overall is clearly the simple square grid.

4. PRACTICAL COMMENTS

Although it is intended to stand by the conclusions given at the ends of sections 2 and 3, some further comments are needed.

So far we have assumed lattices with identical arrays, and in principle one can do better with a variety of array sizes and therefore a selection of detection ranges. This may be illustrated for the detection case, starting from the previous no-overlap condition of touching circles. The gaps between these circles can then be partly filled by smaller touching circles corresponding to shorter and less powerful arrays, the remaining gaps filled by still smaller circles, and so on. Although this is a well-known problem there is one new point that can be made here. Under certain propagation conditions the area cover of an array is directly proportional to the number of hydrophones in the array [1], so that in one sense array efficiency does not depend on its length. Thus in the above packing process the approach to unity of the packing fraction F can be a realistic reflection of the increasing efficiency of the whole system. Under more

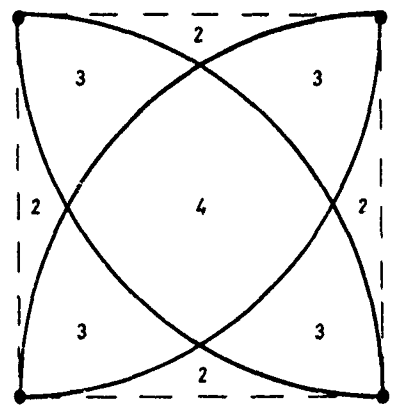

FIG. 3 ELEMENT OF SQUARE LATTICE WITH GEOMETRY FOR FULL CROSS-FIX COVER, SHOWING NUMBERS OF DETECTIONS

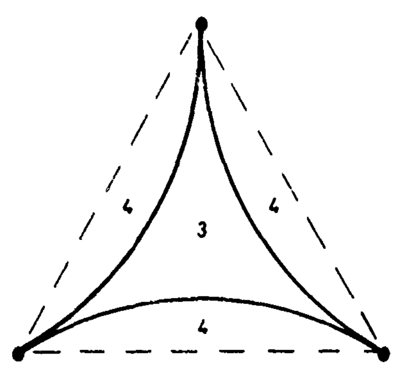

FIG. 4 ELEMENT OF TRIANGULAR LATTICE WITH GEOMETRY FOR FULL CROSS-FIX COVER, SHOWING NUMBERS OF DETECTIONS

general propagation conditions some increase in efficiency may still be possible. It is however very doubtful if this increase is worth the complication involved, and in practice a variety of arrays may only be justified if they fit in with topographic features.

In sections 2 and 3 most weight has been put on the full-cover condition, and although this is reasonable it is worth asking whether small changes in one or other direction may not give a better overall solution. Figure 5 illustrates this point for detection with a square lattice. Near the full-cover condition at $r = d/\sqrt{2}$ the cookie-cutter model gives a parabolic relation between probability and the ratio r/d. Small changes in r/d hardly affect the probability, so that the best operating point should certainly be with $r < d/\sqrt{2}$. Thus even with the cookie-cutter model the decision has to involve judgements on what probability level is worth paying for.

The practical curve relating detection probability to range is usually quite unlike the cookie-cutter. It depends on the propagation conditions, on the variation of source level with the target and with its operating condition, and on many other factors. It may sometimes resemble a Gaussian curve, or perhaps more often a simple exponential decay. The effect on area cover is shown schematically in figure 5. The choice of operating point will again involve operational and economic judgements, but it is still reasonable to choose approximately $r = d/\sqrt{2}$ as regards detection or $r = d$ as regards cross-fixing. Note that the range r now has to be more carefully specified, perhaps as the range where 50% of targets will be detected in a given exposure time.

The smoothing or blurring of the probability versus range curve results in a more general blurring, as already shown in figure 5. The distinction between the point of no overlap or no superfluity and that of full cover vanishes, to be replaced by the continuous curve of probability. It is desired to stress that, in practice, overlap or superfluity are not wasteful unless taken to extremes. Besides serving to increase the probabilities of detection or of cross-fixing, they can in the latter case remove ambiguities[2]. The blurring also tends to make the conclusions at the ends of sections 2 and 3 rather weaker, but it is not thought to invalidate them.

5. CONCLUSIONS

(a) Considering detection alone, the best arrangement of arrays to give area cover is a simple triangular lattice. For full cover, spacing should be $\sqrt{3}$ times the detection range.

(b) For cross-fixing, the area covered is maximised by the academic solution of a triangular lattice of pairs of arrays. The best practical solution is a simple square lattice with spacing approximately equal to the detection range.

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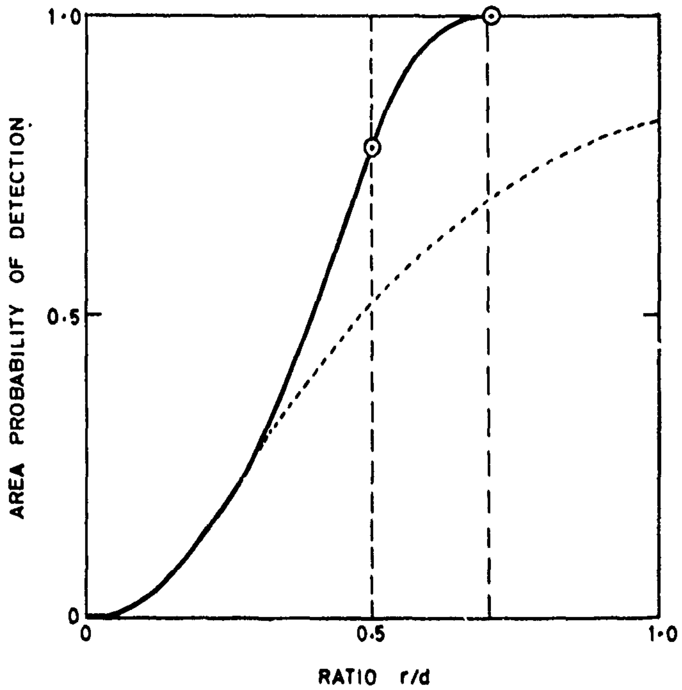

Full line: Cookie-cutter model with circles marking the onset of overlap and the achievement of full cover.

Dotted line: Schematic for practical probability range model.

FIG. 5 DETECTION COVER FOR A SQUARE LATTICE AS A FUNCTION OF THE RATIO OF DETECTION RANGE r TO SPACING d

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